A Novel Watermarking Method Based on Sub-band Coefficient Encoding in DCT Domain

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Abstract

This paper presented a novel watermarking method to embed a watermark into an image. To improve the transparency and robustness of watermark embedding, a visual model was employed to calculate the block based just noticeable difference (JND), and the three sub-bands of coefficient matrix in the medium frequencyof block discrete cosine transform (BDCT) were defined to embed objects. Firstly, an original watermark file was transferred into a binary watermark sequence, which was encoded by redundant encoding method and scrambled randomly if necessary. Then, two neighboring image blocks were selected each time from the host image by Hilbert scanning order, and transformed by BDCT. According to the JND and the watermark bit, the BDCT sub-band coefficients at same region of two neighboring blocks were adjusted to embed the watermark. Lastly, the inverse BDCT was executed to get the embedded image. The experiments show that the embedded watermark is invisible, and the algorithm is robust to common image processing operations.

Keywords

Image Watermarking; Just Noticeable Difference; Redundant Encoding; Block Discrete Cosine Transform; Sub-Band Coefficient Encoding

Introduction

Along with the increasingly requirement of the information security, the watermarking technique is much accounted. Specifically, the digital image watermarking technique have gain momentum , in order to embed watermark within an image and to claim the copyright. For an effective image watermarking scheme, three basic requirements should be satisfied: transparency, robustness and security. The former two are in conflict with each other. To dissolve this conflict availably, the masking characteristic of human visual system (HVS) can be utilized(M. Barni, et al, 2001). Generally, image watermarking algorithms are classified into two types. One works in spatial domain, and the other works in the transform domain, such as DCT or DWT. In addition, the latter is more desirable because the energy of embedded secret bits in transform domain is spread over all areas of image in the spatial domain. A good watermarking technique also should extract the watermark from embedded image blindly.

At recent years, many algorithms based on DCT have been proposed for watermarking (from M. Barni, et al, 2001 to Feng M.Y., et al, 2008). But most are based on the relationship of inner block. Due to the neglection of the relativity of two neighboring blocks of DCT domain, the modification of coefficients in inner block may cause blocking effects. Usually, two adjacent blocks can be acquired by scanning the image along row direction or column direction. However, it only uses one dimensional correlation of an image. The Hilbert scanning whose curve can be found in Xiang's dissertation (Xiang H., 1999), can commendably reserve two dimensional correlation of an image.Therefore, it is selected in our algorithm to get two adjacent blocks. Yang (Yang H.F., et al, 2003) and Sun (Sun Q.D., et al, 2008) has proposed a coefficient mean adjustment algorithm of two corresponding detail sub-bands between the two neighboring blocks in DWT domain. Because the detail sub-band of DWT reflects the high frequency information of an image, the algorithm has an innate defect which is sensitive to low-pass filter.

In this paper, an adaptive watermarking method has been put forward based on block DCT and visual model, which supports embedding a short text or a small binary image into the image. As mentioned before, to adjust the input image for transparent watermarks, a visual model (Yang H.F., et al, 2003; Sun Q.D., et al, 2008) is employed to calculate different

JND thresholds to determine the intensity of watermarking at different locations of image. Watermark embedding as well is given a redundancy encoding method for its robustness.

Visual Model and JND

Visual Model

Under the background gray *f*, the human eyes relative sensitivity to gray change $\gamma(f)=\Delta f/f$, which is a non-linear function of *f*, can be approximated by the equation as follows (Sun Q.D., 1998):

$$\gamma(f)=\frac{\Delta f}{f}=0.02\left[\mathrm{e}^{\frac{128}{f}-1}+\mathrm{e}^{\frac{1}{(256-f)}-\frac{1}{128}}\right] \tag{1}$$

where *e* is the base of natural logarithm. In experiment, we can use the gray mean of $K\times K$ image block $\boldsymbol{B}_{uv}$ located at (u, v), i.e. $f=\mathrm{mean}(\boldsymbol{B}_{uv})$.

Block Size and DCT Sub-Band Selection

According to HVS, it is better for the transparent of watermarking to embed the watermark into the coefficients of higher frequency in DCT domain. But considering the robustness of watermarking against the low-pass filter, high-pass filter and JPEG compression etc., it is better that the watermark is embedded into coefficients of medium frequency in DCT domain (Jung H.S., et al, 2002). Although the image block size can be 8×8, 4×4 or 2×2, the experiments show that the algorithm given below will give more attention to two properties of transparent and robustness when the block size is settled as 4×4. On the basis of the above, we should embed the watermark into the lower medium or higher medium frequency areas of DCT domain as masks as follows.

Lower medium masks (LM):

$$\boldsymbol{M}(1)=\begin{bmatrix}0&0&1&1\\0&0&0&0\\0&0&0&0\\0&0&0&0\end{bmatrix},\ \boldsymbol{M}(2)=\begin{bmatrix}0&0&0&0\\0&1&1&0\\0&1&0&0\\0&0&0&0\end{bmatrix},\ \boldsymbol{M}(3)=\begin{bmatrix}0&0&0&0\\0&0&0&0\\1&0&0&0\\1&0&0&0\end{bmatrix}$$

or higher medium masks (HM):

$$\boldsymbol{M}(1)=\begin{bmatrix}0&0&0&1\\0&0&0&1\\0&0&0&0\\0&0&0&0\end{bmatrix},\ \boldsymbol{M}(2)=\begin{bmatrix}0&0&0&0\\0&0&1&0\\0&1&1&0\\0&0&0&0\end{bmatrix},\ \boldsymbol{M}(3)=\begin{bmatrix}0&0&0&0\\0&0&0&0\\0&0&0&0\\1&1&0&0\end{bmatrix}$$

Therefore, the DCT-transformed coefficient matrix of image block $\boldsymbol{B}_{uv}$ can be separated into three medium frequency sub-bands:

$$\boldsymbol{F}_{u,v}^{s}=\mathbf{DCT}(\boldsymbol{B}_{uv}).*\boldsymbol{M}(s)\qquad s=1,2,3 \tag{2}$$

where DCT(*) stands for DCT transform, the operator ".*" stands for element-by-element product.

Just Noticeable Difference (JND)

To ensure that the watermark has good transparency and robustness, JND can be used to adjust the intensity of watermark-embedding (M. Barni, et al, 2001; Feng M.Y., et al, 2008; Yang H.F., et al, 2003; Sun Q.D., et al, 2008). The JND of image block $\boldsymbol{B}_{uv}$ is defined as follows:

$$\boldsymbol{J}_{uv}=(b-a)\frac{\boldsymbol{T}_{uv}-\min(\boldsymbol{T})}{\max(\boldsymbol{T})-\min(\boldsymbol{T})}+a \tag{3}$$

where $\boldsymbol{T}_{uv}$ is a normalized value of $\boldsymbol{T}'_{uv}=f\gamma(f)\boldsymbol{E}_{uv}$ at the range $[a, b]$, while $\boldsymbol{E}_{uv}$ is the normalized entropy of $\boldsymbol{B}_{uv}$ (Sun Q.D., et al, 2008).

Image Watermarking Method

Watermark Embedding

Let $\boldsymbol{W}$ represents a secret bit sequence or watermark sequence, $\boldsymbol{B}_{uv1}$ and $\boldsymbol{B}_{uv2}$ are the two neighboring image blocks and their DCT-transformed detail sub-bands are $\boldsymbol{F}_{uv1}^{s}$ and $\boldsymbol{F}_{uv2}^{s}$ (simply marked by $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$, or by a universal symbol $\boldsymbol{F}_t$, $t\in\{1, 2\}$). Now the admissible distortion factor of sub-band coefficients of DCT can be defined as follows:

$$\lambda_t=\frac{|\boldsymbol{F}_t|+\delta}{\mathrm{mean}(|\boldsymbol{F}_t|)+\delta}\qquad t\in\{1,2\} \tag{4}$$

where δ is a small positive number to avoid denominator being zero. It is also an effect factor of absolute values of sub-band coefficients to embedding intensity. Its value will impact the quality of embedded image and the veracity of recovered watermark.

It is also assumed that μ is the mean value of JNDs of two neighboring blocks, Δd is their corresponding DCT sub-band coefficients difference under same mask, and $\boldsymbol{\varepsilon}$ is the adjustment intensity matrix of sub-bands coefficients. They are represented by following equations respectively:

$$\mu=\frac{1}{2}\left(\boldsymbol{J}_{uv1}^{s}+\boldsymbol{J}_{uv2}^{s}\right) \tag{5}$$

$$\Delta d=\mathrm{Sign}(\boldsymbol{W}_k)[\mathrm{mean}(\boldsymbol{F}_2)-\mathrm{mean}(\boldsymbol{F}_1)] \tag{6}$$

$$\boldsymbol{\varepsilon}_t=\frac{1}{2}\mathrm{Sign}(\boldsymbol{W}_k+t)\lambda_t(\mu-\Delta d) \tag{7}$$

where Sign(•) is a sign function. $\boldsymbol{W}_k$ is the *k*-th element of binary watermark sequence $\boldsymbol{W}$. Currently, the following equation is regarded as the watermark embedding rule:

$$\boldsymbol{F}_t'=\begin{cases}\boldsymbol{F}_t+\boldsymbol{\varepsilon}_t & \text{if } \Delta d<\mu\\ \boldsymbol{F}_t & \text{otherwise}\end{cases} \tag{8}$$

This rule can ensure the embedded image having such a eature of mean($F_1^{'}$)≥mean($F_2^{'}$) when W_k =1 and mean($F_1^{'}$)<mean($F_2^{'}$) when W_k =0, which enables the algorithm to recover the embedded watermark easily.

From the embedding rule, it is well known that the two corresponding sub-bands can be embedded with a bit of watermark. Thus, if the size of carrier image is $M \times N$, the watermark repeatedly embedding capacity of this algorithm can reach the value of $(3MN)/(2K^2)$ bitswhich is large enough to embed watermark into an image and can bring an enough redundancy to ensure the watermark's robustness.

Watermark Extraction

Being the same with watermark embedding, the blind extraction rule can be proved as follows:

$$\hat{W}_k = \begin{cases} 1, & \text{if } \operatorname{mean}(\hat{F}_1) \geq \operatorname{mean}(\hat{F}_2) \\ 0, & \text{else} \end{cases} \tag{9}$$

where $\hat{F}_t$ is the DCT sub-bands of embedded image block, $\hat{W}$ is the secret bit sequence extracted from embedded image block.

Embedding Algorithm

1) ***Step 1***

Select the medium frequency masks.

2) ***Step 2***

Whether the embedded watermark is a text file, an image or other source, it will always be converted into a bit sequence Wwhich is called the original watermark.

3) ***Step 3***

To improve the robustness of watermarking, the redundancy of embedded watermarks should be guaranteed. In other words, the watermark should be embedded repeatedly. So the original watermark W should be extended periodically as follows:

$$W_{\text{ex}}^m = W_l \quad \begin{cases} m = n \cdot L + l; n = 0,1,\cdots,Cr-1; \\ l = 0,1,\cdots,L-1 \end{cases} \tag{10}$$

where W_{ex} is the extended watermark, W_{ex}^m represents its m-th element, Cr is the extended factor.

4) ***Step 4***

To improve the security of watermarking, W_{ex} may be scrambled randomly.

5) ***Step 5***

In order to keep the relativity of two neighboring image blocks, the original host image can be scanned by Hilbert scanning algorithm to obtain a Hilbert scanning sequence.

6) ***Step 6***

The two neighboring image blocks B_{uv1} and B_{uv2} are selected each time from the host image with Hilbert scanning order, and the watermark is embedded according to the method as mentioned above in this section until all DCT sub-bands of all blocks have been processed.

7) ***Step 7***

After the inverse DCT for all watermark embedded blocks is applied, a embedded image I' can be obtained.

Extraction Algorithm

1) ***Step 1***

Select the same medium frequency masks as that in watermark embedding.

2) ***Step 2***

Scan the embedded image I' by Hilbert scanning with the same order as that in watermark embedding.

3) ***Step 3***

Two neighboring image block B'_{uv1} and B'_{uv2} are selected each time from the embedded image with Hilbert scanning order, and the watermark is extracted according to the method as mentioned above in this section until all DCT sub-bands of all blocks have been processed.

4) ***Step 4***

Now we can get a watermark sequence $\hat{W}_{\text{ex}}$, which involves the Cr copies of original watermark.

5) ***Step 5***

If there was a scrambling when watermark was embedded, here we should do unscrambling to $\hat{W}_{\text{ex}}$.

6) ***Step 6***

The final watermark can be obtained from $\hat{W}_{\text{ex}}$ as follows:

$$\hat{W}_l = \begin{cases} 1, & \text{if } \sum_{n=0}^{Cr-1} \hat{W}_{\text{ex}}^{n \cdot L + l} \geq \dfrac{Cr}{2} \\ 0, & \text{else} \end{cases} \tag{11}$$

7) *Step 7*

The binary watermark sequence $\hat{W}$ should be converted back into a file with the same format as original source.

Simulation Results and Analysis

The peak signal to noise ratio (PSNR) is employed to evaluate the quality of watermark embedded image, and the bit error rate (BER) is employed to evaluate the quality of recovered watermark, meanwhile the normalized correlation coefficient between the extracted watermark and the original one is employed to evaluate the quality of watermarking technique.

In the experiment, the proposed algorithm is evaluated on the images "Lena" and "Boat" (512×512). The block size K can be 8, 4 or 2. By testing and comparing with each other, when K is 4, the comprehensive characteristic of watermarking is the best,so that we set K=4. Theoretically, using the LM masks to modify the coefficients of BDCT will lower down the PSNR of host image, but it is not sensitive to those image processing operations impacting its high frequency property. On the contrary, using the HM masks to modify the coefficients of BDCT may not lower down the PSNR of host image, but it is sensitive to those image processing operations impacting its high frequency property.

FIG. 1 is the relationship curves between PSNR of embedded image and the effect factor δ using two masks. Apperantly, the PSNR of HM is better than that of LM.

FIG. 2 is the relationship curves between BER of the recovered watermark bits and δ. When δ⊚ ≤0, the BERs of two masks are consistent, but when δ⊚ >0, the BER of HM obviously moves up quickly compared with that of LM.

FIG. 3 is the relationship curves between PSNR and the JND normalized range [a, b] at full capacity embedding. From this figure, similar conclusion to Fig. 1 is made.

FIG. 4 is the relationship curves between BER and [a, b]. Although, a curve has just been observed in this figure, but there are two overlapped curves actually.

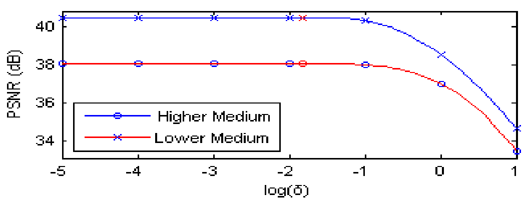


FIG. 1 RELATIONSHIP BETWEEN PSNR AND δ

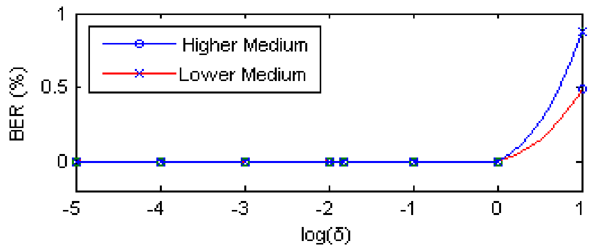


FIG. 2 RELATIONSHIP BETWEEN BER AND δ

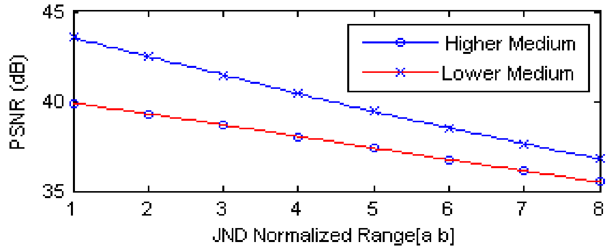


FIG. 3 RELATIONSHIP BETWEEN PSNR AND [a, b] (b=a+1)

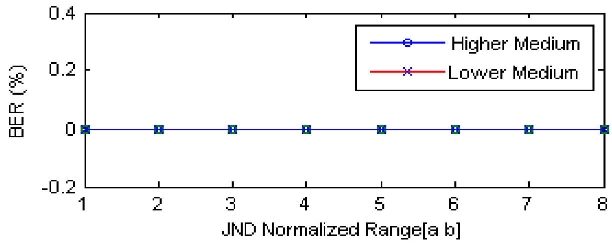


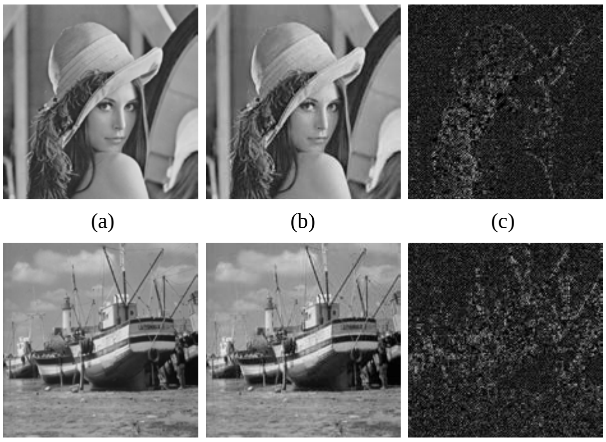
FIG. 4 RELATIONSHIP BETWEEN BER AND [a, b] (b=a+1)

The effect factor⊚ is an important control parameter in the algorithm. As shown in FIG. 1 and FIG. 2, the smaller ⊚ is, the better PSNR is, and the lower BER is. So that we set ⊚ =0.015. As shown in FIG. 3, the PSNR is almost in inverse proportion to [a, b]. The smaller [a, b] is, the higher PSNR is, and the better invisibility of embedded watermark is. In FIG. 4, the difference of two masks in BERs is absent, but as known in section II, the smaller [a, b] will bring down on the embedding intensity, resulting in that the performance of recovering algorithm will be worse, and the BER will be higher. So that an appropriate [a, b] is better. Here, we set [a, b]=[4, 5].

FIGs. 5(a) and 5(d) are the original images of "Lena" and "Boat" respectively. FIGs. 5(b) and 5(e) are their watermark embedded results of 1536 bytes text, and their PSNRs are 38.0dB and 34.2dB. FIGs. 5(c) and 5(f) are their differences between the original images and embedded images at the condition of magnification 30 times. As shown in FIG. 5, the embedded watermark in different embedded image is invisible though the PSNR is a little low. The algorithm can fully extract the embedded watermark from the embedded image.

In the experiment, almost all attack items are operated on Photoshop 6.0, besides the JPEG compression, central region cropping and weighted arithmetic average filter. FIG. 6 is the binary image watermarking

results of the proposed algorithm acting on the image "Lena" when LM masks are in use. FIG. 6(a) is the original binary watermark image (32×32). FIG. 6(b)~(i) are the recovered copies from the watermarked image by attack of cropping the central region with size 300×300, and then zoomed out to size 256×256 and zoomed in, JPEG compression with 70% quality, afterward, Gaussian noise is added with 5%, extrusion distortion with 20% degree, contrast enhancement with 50%, 10 times edge enhancement and weighted arithmetic average filter respectively. As shown in FIG. 6 and TABLE 1, the proposed watermarking algorithm is also available to fit hiding information, and it is robust against the general image processing.



(a) (b) (c) (d) (e) (f)

FIG. 5 WATERMARK EMBEDDED RESULTS OF "LENA" AND "BOAT"

(a) (b) (c) (d) (e) (f) (g) (h) (i)

FIG. 6 WATERMARKING RESULTS OF A BINARY IMAGE

In the experiment, we also give the zero BER tests of attack defense of short text watermarking "SSPU COPY" and its performance is in comparison with that of binary image watermarking. As shown in Table 1, the robustness of short text watermarking is better than that of binary image, due to its more redundancy at the same condition. It is also found that the robustness of the algorithm using the LM masks is better than that using the HM masks, especially in the last three attack items.

TABLE 1 ZERO BER ATTACK DEFENSE TESTS AND COMPARISONS OF DIFFERENT MASK AND DIFFERENT WATERMARK STYLE

The Normalized Correlation Coefficient				
Attack items	***Short text ("SSPU COPY")***		***Binary image (As shown in Fig.6)***	
	LM	***HM***	***LM***	***HM***
Brightness enhancement (100%)	1	1	1	1
Contrast enhancement (70%)	1	1	0.9975	0.9975
Edge enhancement (10times)	1	1	1	1
Histogram equalization	1	1	1	1
Extrusion distortion (100%)	1	1	0.7633	0.7806
Eddy distortion (100°)	1	1	0.7725	0.7744
Add Gaussian noise (10%)	1	1	0.8033	0.7863
Add uniformity noise (10%)	1	1	0.9801	0.9752
Add salt & pepper noise (10%)	1	1	1	0.9975
Cropping in central region (350×350)	1	0.9792	0.7084	0.7084
Zoom out and Zoom in (256×256)	1	0.8889	0.9177	0.6962
JPEG compression (70% quality)	1	0.6816	1	0.5691
Weighted arithmetic average filter	1	0.6736	0.9975	0.7791

We also compare our algorithm with Yang's method mentioned in the reference (Yang H.F., et al, 2003) and give the results of zero BER tests of attack defenses as shown in TABLE 2. For the 10 attack items that precede, they have almost same propertieswith little bit differences. But for the rearmost 3 attack items, apparently, the properties of our method overmatches that of Yang's method.

Conclusions

This paper presented a novel watermarking method based on BDCT for short text or small binary image watermarking. In our approach, the comparability of three sub-bands of DCT was considered, in order to improve the transparency of watermarking, the visual model was also used to determine the embedding intensity at different locations. In addition, in order to defense the general image processing attacks, the redundant encoding was given to increase the embedded copies of watermark. The experiment results demonstrated that the proposed algorithm has yielded the acceptable performance on transparency and robustness aganist general image attacks, and it is also not sensitive to JPEG compression, low-pass filter

and high-pass filter when using the LM masks.

TABLE 2 ZERO BER ATTACK DEFENSE TESTS AND COMPARISON OF PROPOSED METHOD AND YANG'S METHOD

The Normalized Correlation Coefficient (Binary Image Watermarking)		
Attack items	***Proposed method***	***Yang's Method***
Brightness enhancement (100%)	1	1
Contrast enhancement (70%)	0.9975	0.9950
Edge enhancement (10times)	1	1
Histogram equalization	1	1
Extrusion distortion (100%)	0.7633	0.7827
Eddy distortion (100°)	0.7725	0.7870
Add Gaussian noise (10%)	0.8033	0.6971
Add uniformity noise (10%)	0.9801	0.9454
Add salt & pepper noise (10%)	1	0.9825
Cropping in central region (350×350)	0.7084	0.7217
Zoom out and Zoom in (256×256)	0.9177	0.4477
JPEG compression (70% quality)	1	0.6646
Weighted arithmetic average filter	0.9975	0.8265

ACKNOWLEDGMENT

This work was supported by a grant from the Technological Innovation Foundation of Shanghai Municipal Education Commission (No. 09YZ456) and the Key Disciplines of Shanghai Municipal Education Commission (No. J51801).

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